

# Musical Notation & Representation

Music 253/CS 275a  
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5 Jan 2016

# Representing Music

Two main categories:

- For **Performance** (used as memory aid and for non-aural transmission)

Usually not a complete representation (some discretion left to performer)

- Usually written, but also Guidonian hand is a spatial representation of music for education and memorization.

Scores for computational performance (usually no discretion left to computer)

- MIDI files, Record, CD, MP3, Data sonification

- For **Analysis**

Usually highlights a specific aspect of the music (reductive)

- Graphical representations (visualizations)
- Digital representations (computational analysis)
- Audio-based analysis (such as spectrograms)

# Oldest Known Music Notation

Old Babylonian cuneiform musical notation. 2000-1700 BC



2 double columns, each of 7 ruled lines with numbers in Old Babylonian cuneiform tablature notation, with headings, "intonation" and "incantation", respectively.

Two ascending 7-note scales to be played on a 4-stringed lute tuned in ascending fifths.



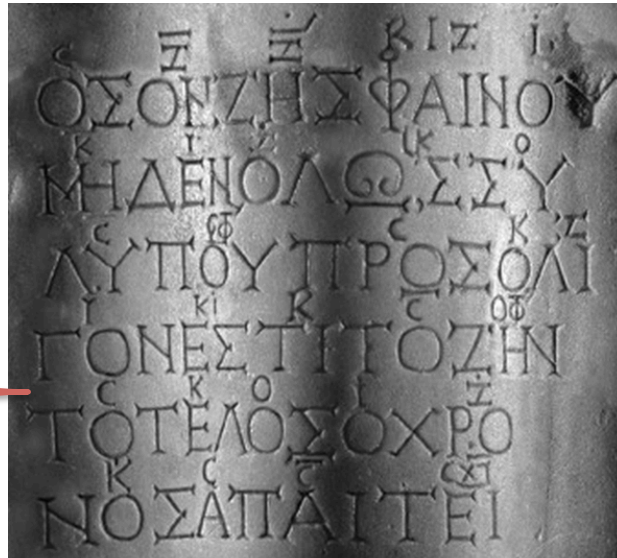
[http://www.schoyencollection.com/music\\_files/ms5105.jpg](http://www.schoyencollection.com/music_files/ms5105.jpg)

<http://www.schoyencollection.com/music.html>

# Music Notation in Ancient Greece

Oldest complete notated song (~1<sup>st</sup> century AD)

Seikilos epitaph



$\bar{C}$   $\bar{Z}$   $\dot{\bar{Z}}$   $KIZ$   $\dot{\bar{I}}$   
 Ὅ σον ζῆς φαί νου

$\bar{K}$   $I$   $\dot{Z}$   $\dot{\bar{K}}$   $O$   $\bar{C}$   $\dot{\bar{O}}\Phi$   
 μη δέν ὄ λως σὺ λυ ποῦ

$C$   $K$   $Z$   $I$   $\dot{K}$   $\dot{K}$   $\bar{C}$   $\dot{\bar{O}}\Phi$   
 πρὸς ὀ λί γον ἐσ τὶ τὸ ζῆν

$C$   $K$   $O$   $I$   $\dot{Z}$   $\dot{K}$   $C$   $\bar{C}$   $\dot{\bar{C}}\dot{\bar{X}}\dot{\bar{\Gamma}}$   
 τὸ τέ λος ὀ χρό νος ἀπ αι τεῖ.



# Music Notation in Ancient Greece

C  $\bar{Z}$   $\dot{\bar{Z}}$  K I Z  $\dot{\bar{I}}$

Ὁ σον ζῆς φαί νου  
While you live, shine

$\bar{K}$  I  $\dot{Z}$   $\dot{\bar{I}}\bar{K}$  O  $\bar{C}$   $\bar{O}\Phi$

μη δὲν ὄ λως σὺ λυ ποῦ  
Have no grief at all

C K Z  $\dot{I}$   $\dot{K}\dot{I}$   $\bar{C}$   $\bar{O}\Phi$

πρὸς ὀ λί γον ἐσ τὶ τὸ ζῆν  
Life exists only for a short while

C K O  $\dot{I}$   $\dot{Z}$   $\dot{K}$  C  $\bar{C}$   $\bar{C}\dot{X}\bar{\Gamma}$

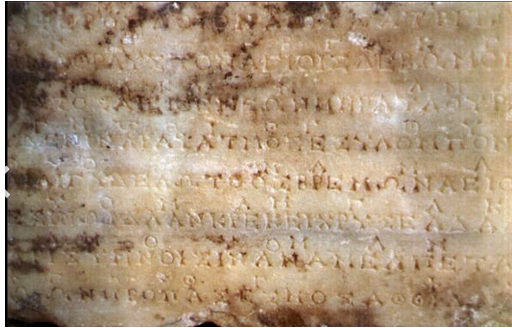
τὸ τέ λος ὁ χρό νος ἀπ αι τεῖ.  
And time demands its toll



[http://en.wikipedia.org/wiki/Seikilos\\_epitaph](http://en.wikipedia.org/wiki/Seikilos_epitaph)

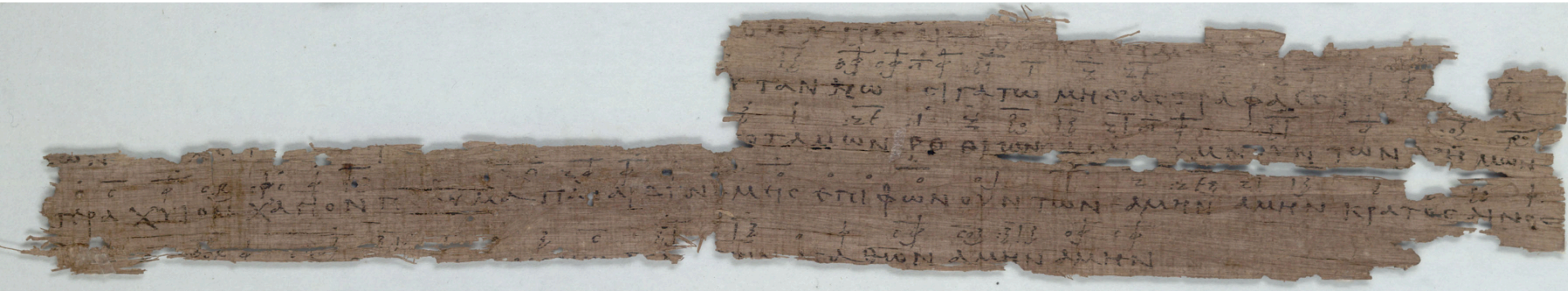
Performed on a *hydraulis*: [https://www.youtube.com/watch?v=P4\\_iWkP24Ww#t=7](https://www.youtube.com/watch?v=P4_iWkP24Ww#t=7)

# Music Notation in Ancient Greece



2<sup>nd</sup> century BC  
Earliest surviving composition  
with a known composer  
(Athenios son of Athenios)

[http://en.wikipedia.org/wiki/Delphic\\_Hymns](http://en.wikipedia.org/wiki/Delphic_Hymns)



[http://en.wikipedia.org/wiki/Oxyrhynchus\\_hymn](http://en.wikipedia.org/wiki/Oxyrhynchus_hymn)

3<sup>rd</sup> century AD

[http://en.wikipedia.org/wiki/Music\\_of\\_ancient\\_Greece](http://en.wikipedia.org/wiki/Music_of_ancient_Greece)



# Tonic Sol-Fa

## The Lamb.

WILLIAM BLAKE.

GEORGE HENSCHEL.

VOICE.

Lit - tle lamb, who made thee? Dost thou know who

KEY C. { | m .m :m .s | s :r | m .s :d<sup>l</sup> .l }

PIANO.

The image shows a musical score for the song 'The Lamb' by William Blake, set to music by George Henschel. The score is for voice and piano. The voice part is written on a single staff with a treble clef and a 2/4 time signature. The piano part is written on a grand staff with both treble and bass clefs and a 2/4 time signature. The lyrics are 'Lit - tle lamb, who made thee? Dost thou know who'. Below the lyrics is a Tonic Sol-Fa notation: KEY C. { | m .m :m .s | s :r | m .s :d<sup>l</sup> .l }. The notation uses letters m, s, r, d, and l to represent musical notes, with dots and colons indicating rhythm and pitch. The score is printed on aged, yellowed paper with a vertical crease down the center.

# Byzantine Music Notation

(10<sup>th</sup> – 15<sup>th</sup> centuries)

interval notation



Romania, 1823

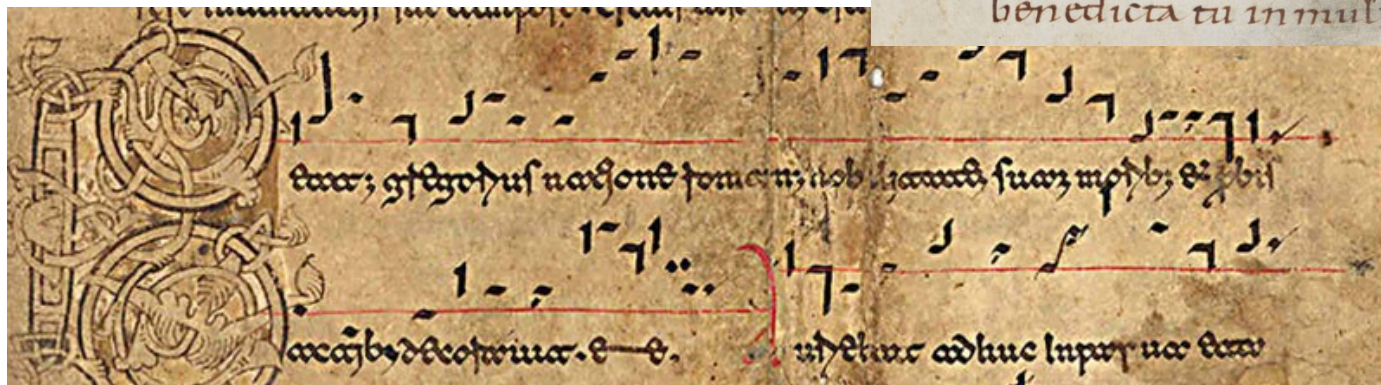
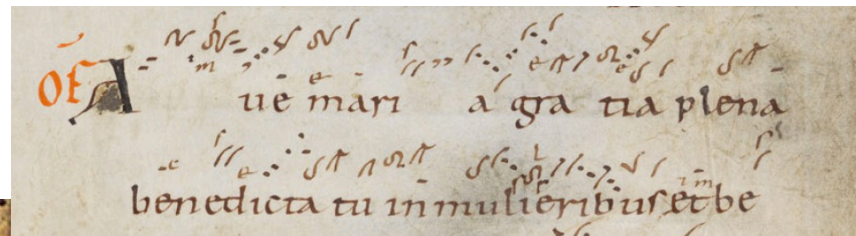
[http://en.wikipedia.org/wiki/Musical\\_notation#Byzantine\\_Empire](http://en.wikipedia.org/wiki/Musical_notation#Byzantine_Empire)



[http://www.musicportal.gr/byzantine\\_music\\_system/?lang=en](http://www.musicportal.gr/byzantine_music_system/?lang=en)



# Gregorian Chant



[http://www.schoyencollection.com/music\\_files/ms1681.jpg](http://www.schoyencollection.com/music_files/ms1681.jpg)

Comm.  
I.

**E** C-CE virgo concí-pi- et, et pá- ri- et fi- li-

← Messine notation

← Modern chant notation

← St. Gall notation

<http://euouae.com/category/transcription/>

[http://en.wikipedia.org/wiki/Gregorian\\_chant](http://en.wikipedia.org/wiki/Gregorian_chant)

<http://en.wikipedia.org/wiki/Neume>



# Shape Notes



16 STAR IN THE EAST 10, 11. Baptist Harmony, p. 35

Hail the blest morn, see the great Mediator,  
 Shepherds, go worship the babe in the manger,  
 Down from the regions of glory descend!  
 Lo, for his guard the bright angels attend. } **CHORUS.**  
 Brightest and best of the sons of the morning!

2 Cold on his cradle the dew-drops are shining;  
 Low lies his bed, with the beasts of the stall;  
 Angels adore him, in slumbers reclining,  
 Wise men and shepherds before him do fall.  
 Brightest and best. &c.

3 Say, shall we yield him, in costly devotion,  
 Odours of Eden, and offerings divine,  
 Gems from the mountain, and pearls from the ocean,  
 Myrrh from the forest, and gold from the mine?  
 Brightest and best. &c.

4 Vainly we offer each ample oblation,  
 Vainly with gold we his favour secure,  
 Richer by far is the heart's adoration:  
 Dearest to God are the prayers of the poor  
 Brightest and best. &c.

Dawn on our darkness, and lend us thine aid; Star in the east, the ho - ri - zon a - dorn - ing, Guide where our infant Re - deemer was laid.

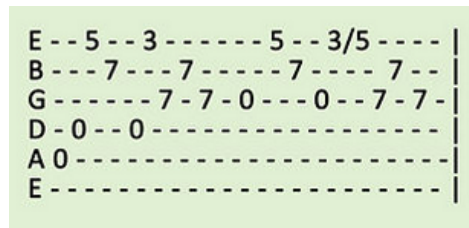
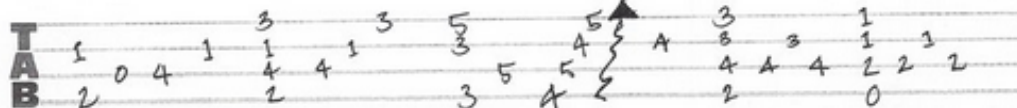
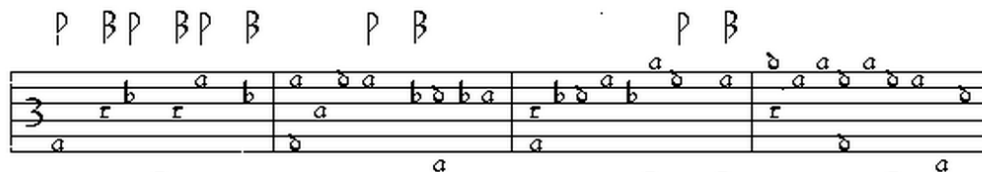


# Tablature

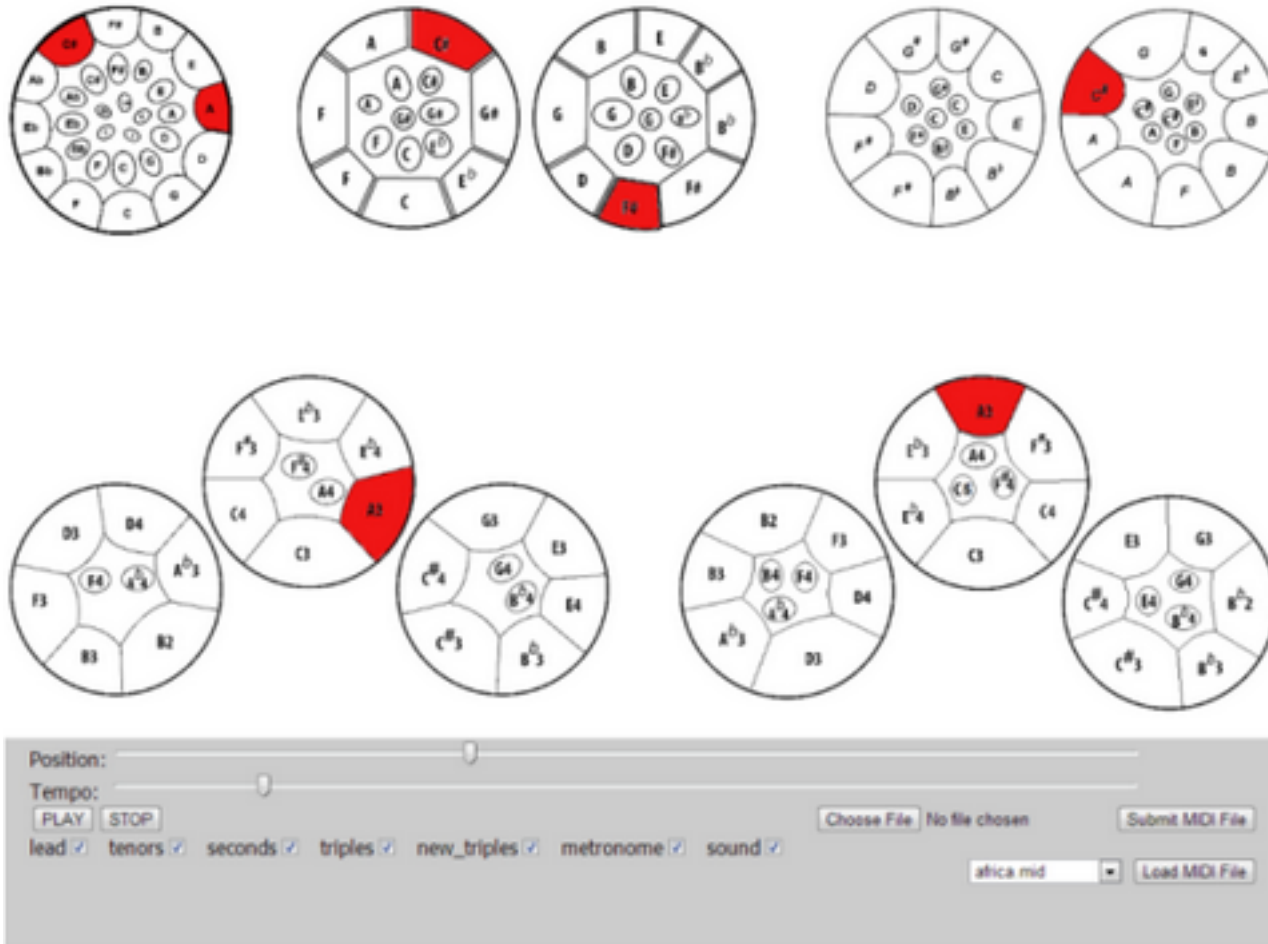
Indicates *how* to play the pitches, not an abstracted/neutral concept of pitch.



lute



# Steel Drum Tablature



— Jonathan Potter, Cardinal Calypso

## Ikuta school notation (Kyoto)



by Kengyō Yatsuhashi (1614–1685)



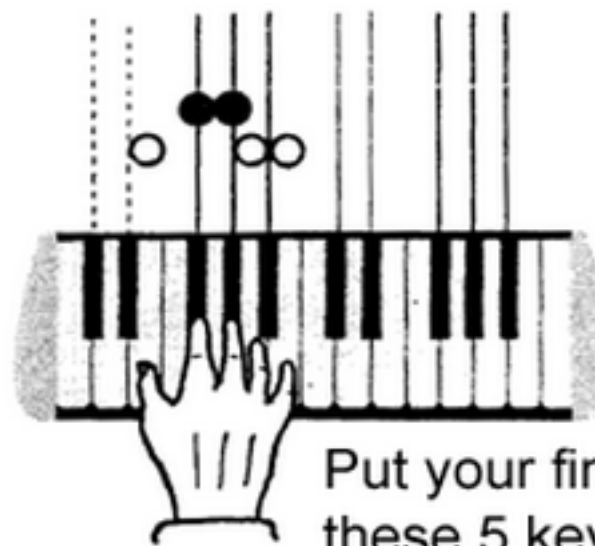
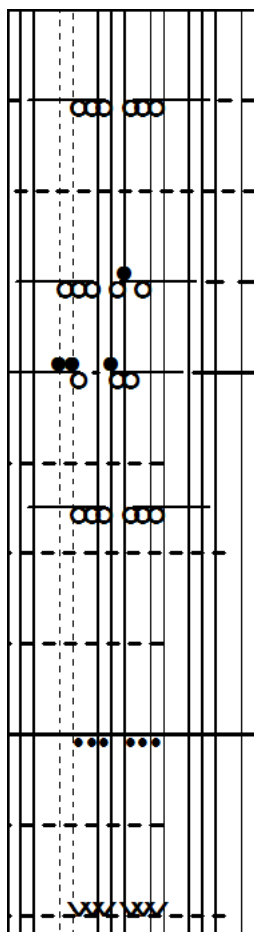
**koto	**kuchi	**kern
*M4/4	*M4/4	*M4/4
=1-	=1-	=1-
{5+i	te	{2d
-	n	.
3	ton	4A
1s	shan	4d: 4G:
=2	=2	=2
0}	.	4r}
{3 sb	sha	{8A: 8A#:
3 sc	sha	8A: 8A#:
8 .	koo	8.a
7	ro	16g
6	rin	8d#
7 o	chin	16gH
.	.	16ah
=3	=3	=3
1c	ton	4d
5 .	koo	8.d
4	ro	16A#
3}	rin	4A}
{1s	shan	{4d: 4G:
=4	=4	=4



# Piano Tablature

## Klavarskribo

“Keyboard script” in Esperanto



Put your fingers above  
these 5 keys

<https://www.youtube.com/watch?v=MlolvxunihA&t=659>

<http://evanlenz.net/blog/2007/11/02/re-discovering-klavarskribo/>

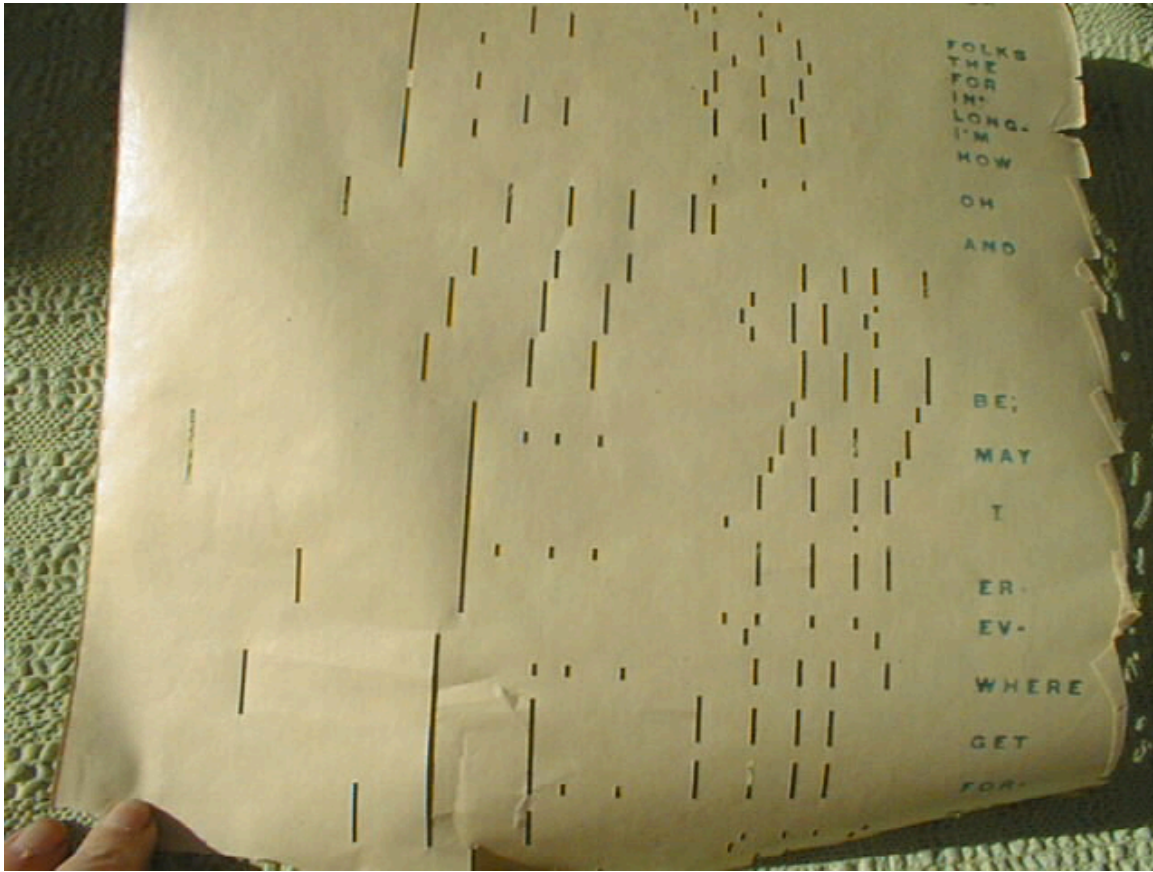
<http://en.wikipedia.org/wiki/Klavarskribo>

<http://www.klavarskribo.nl/en>



# Piano Rolls

Mechanical Representation of music



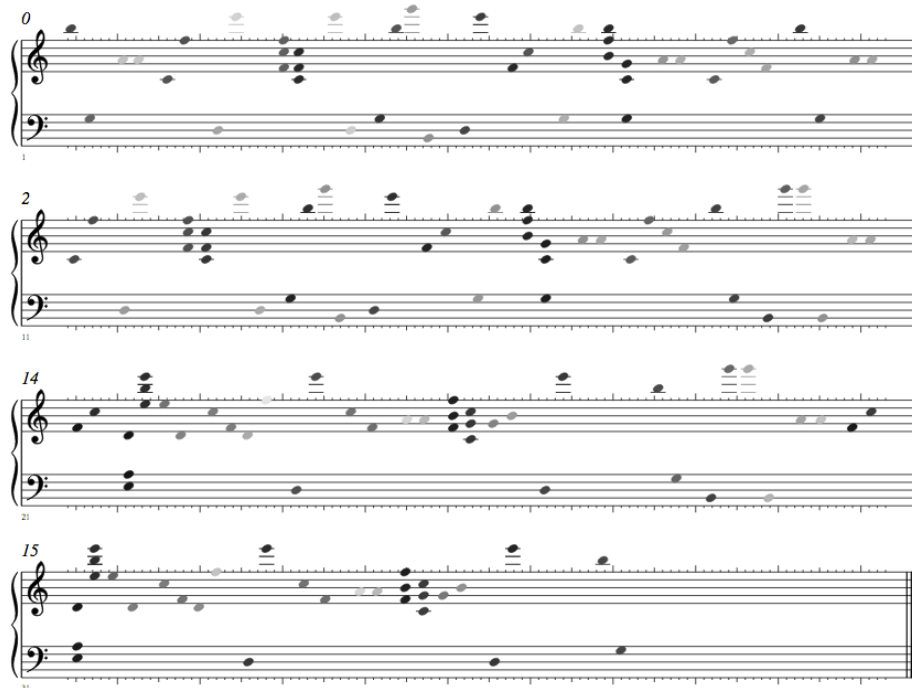
[http://en.wikipedia.org/wiki/Piano\\_roll](http://en.wikipedia.org/wiki/Piano_roll)

<https://www.youtube.com/watch?v=GjpPesy7kIA>

# Performance Data Visualization

Webern Piano Variations, mvmt. 2, (Op. 27)

Anderszewski 1996



Gould 1954



<http://dl.acm.org/citation.cfm?id=2597179>

<http://mazurka.org.uk/webern/notation/Anderszewski1996>

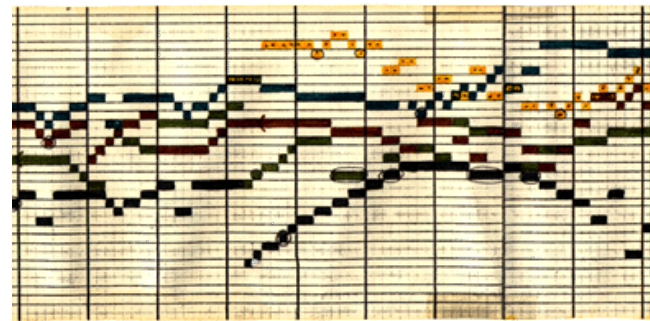
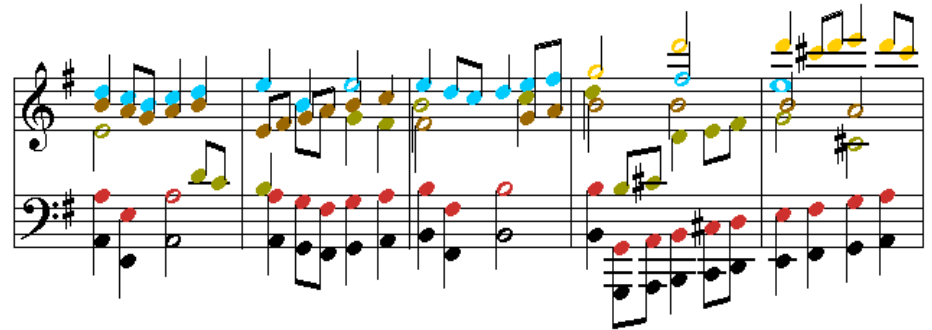
<http://mazurka.org.uk/webern/notation/Gould1954>



# Music Animation Machine

<http://www.musanim.com>

Stephen Malinowski



<https://www.youtube.com/channel/UC2zb5cQbLabj3U9l3tke1pg>

<https://www.youtube.com/playlist?list=PLMOarqHv8B7P1BuvL2iGqkjS1xNrvTiuX>

# Music Animation Machine

Bach, Toccata and Fugue in D minor, organ

[https://www.youtube.com/watch?v=ipzR9bhei\\_o](https://www.youtube.com/watch?v=ipzR9bhei_o)

How are musical  
Dimensions mapped  
In each visualization?

Mozart, Symphony No. 40 in G minor

<https://www.youtube.com/watch?v=xvtoqE33iZg>

Beethoven, Fur Elise

<https://www.youtube.com/watch?v=o0VwTw1eZ1k>

Beethoven, String Quartet No. 16, 1st mvt. (opus 135)

<https://www.youtube.com/watch?v=Lj4kLPgX5QM>

Paganini, Caprice No. 5 (solo violin)

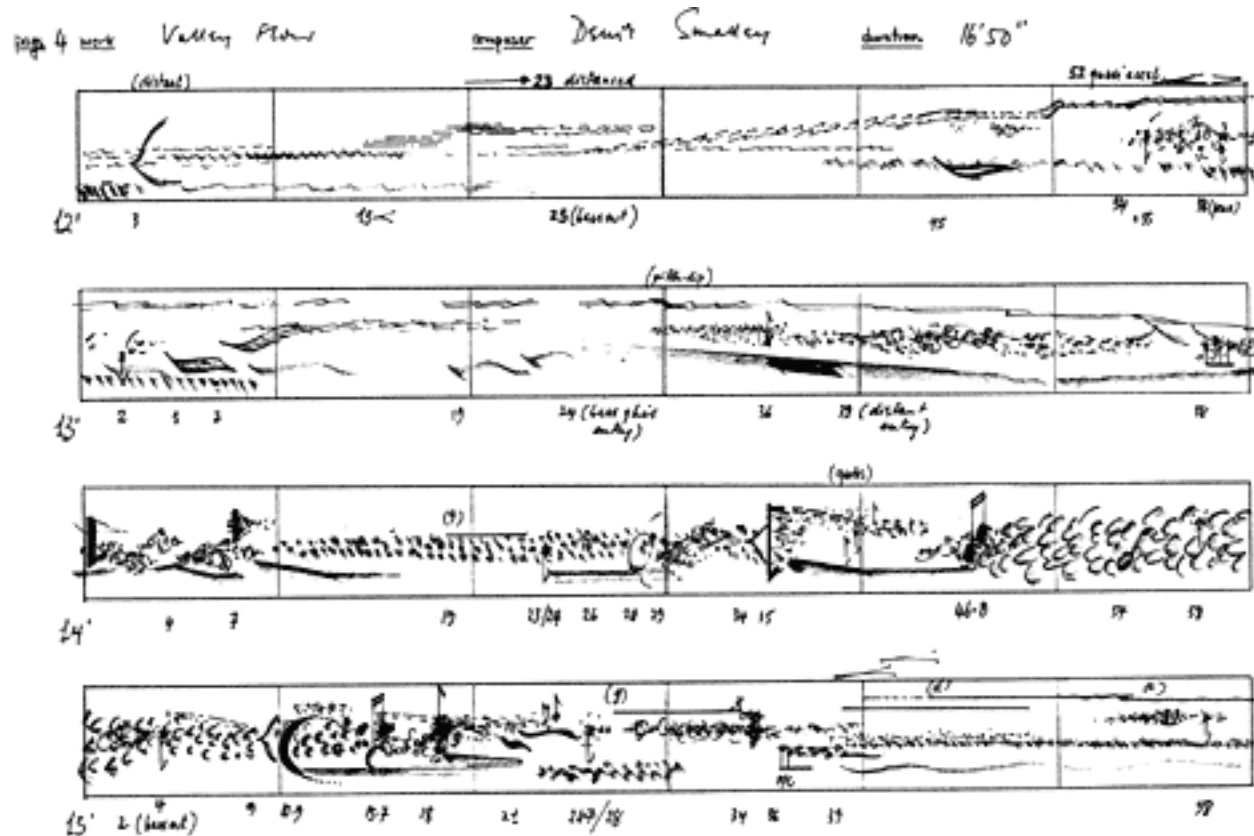
<https://www.youtube.com/watch?v=xhc1PsokFOw>

Debussy, First Arabesque

<https://www.youtube.com/watch?v=Yt1jfX5C1u0>

# Textural Notation

Analytic notation of electro-acoustic music

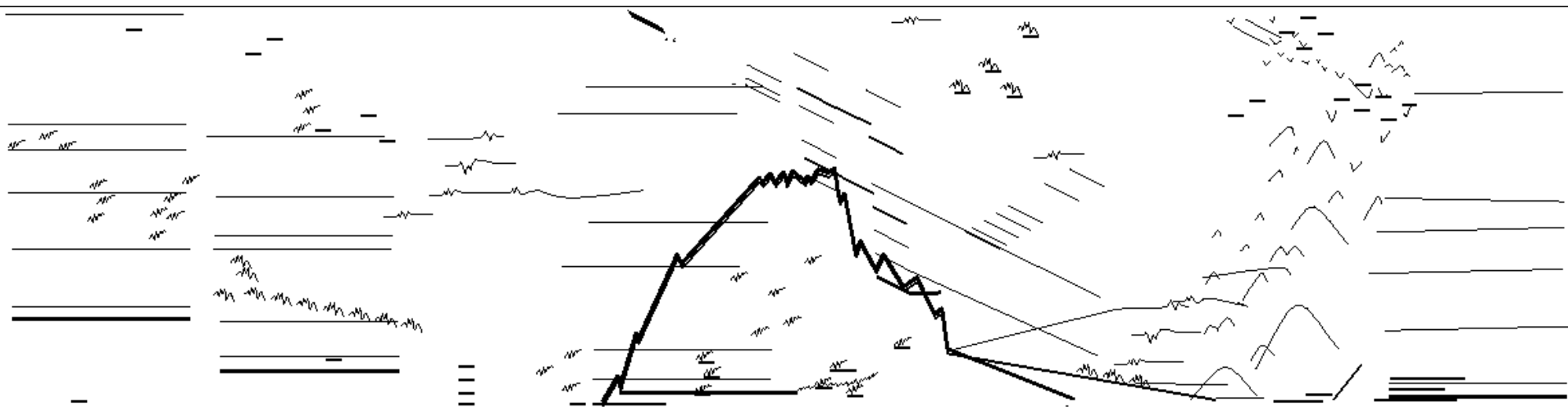


# line2sine

Sonification of vector graphics

<http://sig.sapp.org/projects/all/line2sine/line2sine/examples>

## Example 6:

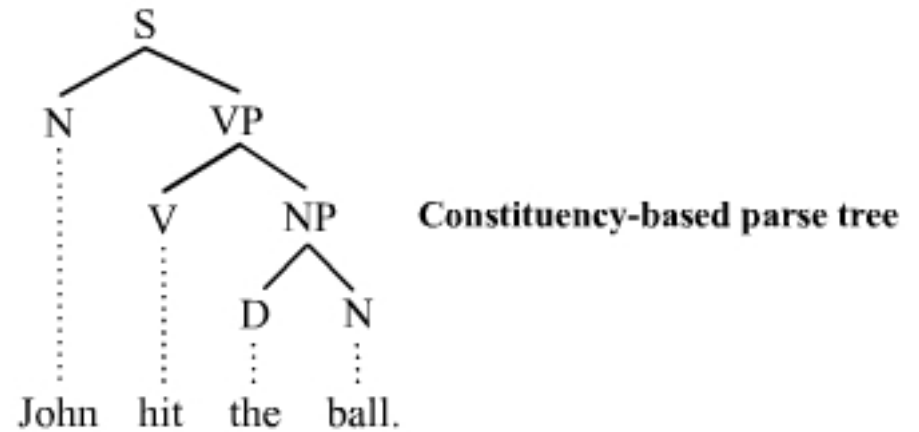
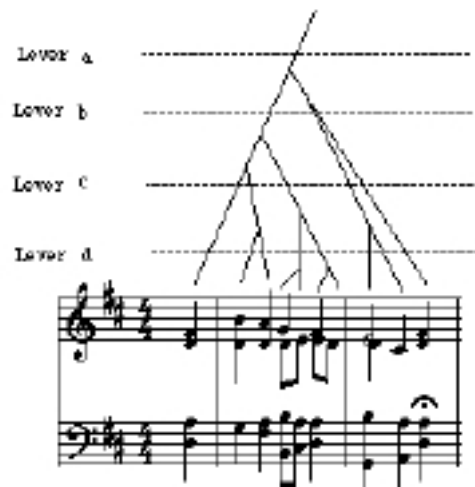


See the music of Iannis Xenakis

[http://en.wikipedia.org/wiki/Iannis\\_Xenakis](http://en.wikipedia.org/wiki/Iannis_Xenakis)



# GTTM



[http://en.wikipedia.org/wiki/Parse\\_tree](http://en.wikipedia.org/wiki/Parse_tree)

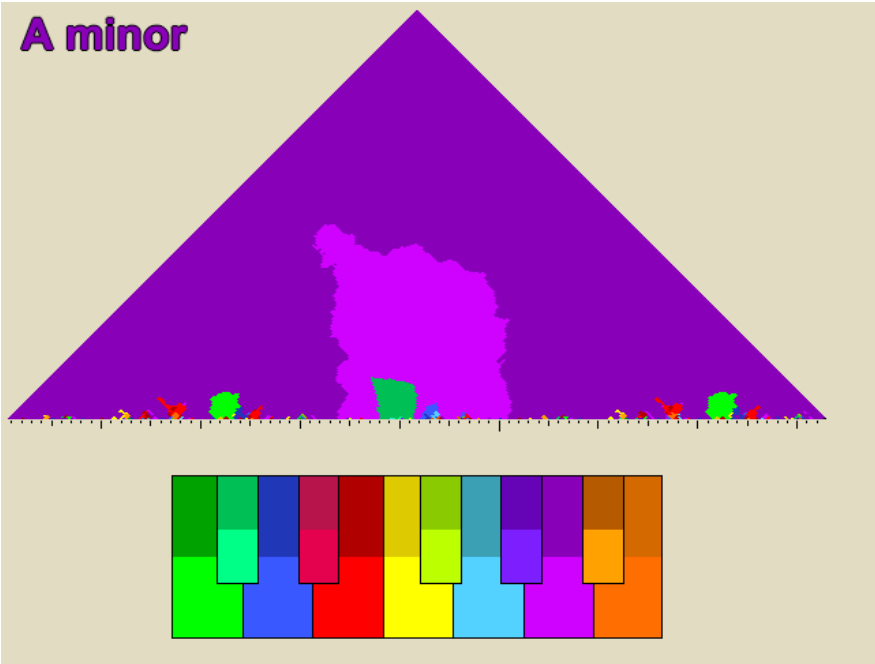
[http://en.wikipedia.org/wiki/Generative\\_theory\\_of\\_tonal\\_music](http://en.wikipedia.org/wiki/Generative_theory_of_tonal_music)



# Keyscapes

Graphical display of harmonic structure

**A minor**



Chopin mazurka in A minor Op. 67, No. 4

<https://www.youtube.com/watch?v=AcxZRI6aews>

A major: 1:18

A minor: 2:10

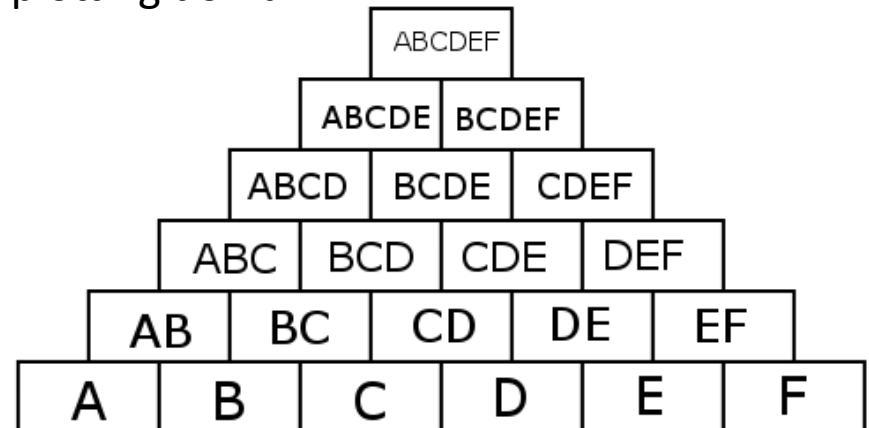
**Landscape:**

background  
large-scale structures  
middleground  
small-scale structures  
foreground  
surface features



An Orchard c1896 Henri Rousseau

Scape plotting domain:



# Computational Key Identification



<http://extras.humdrum.org/man/keycor>

# Computational Key Identification



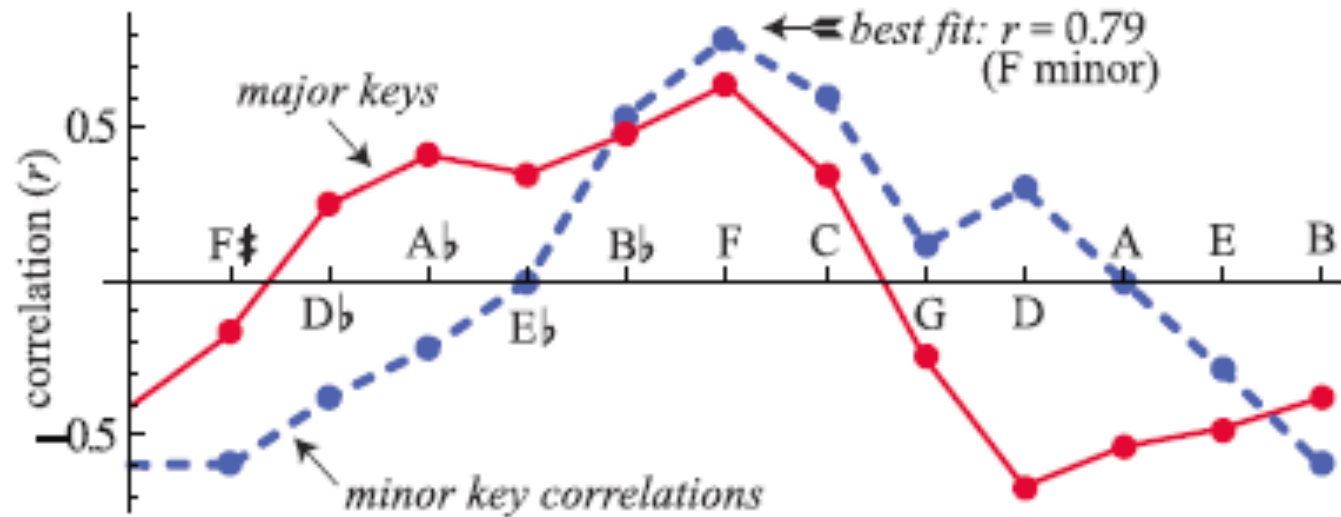
Pearson correlation:

$$r(x, y) = \frac{\sum_n (x_n - \bar{x})(y_n - \bar{y})}{\sqrt{\sum_n (x_n - \bar{x})^2 \sum_n (y_n - \bar{y})^2}}$$

Krumhansl-Schmuckler  
key-finding algorithm:

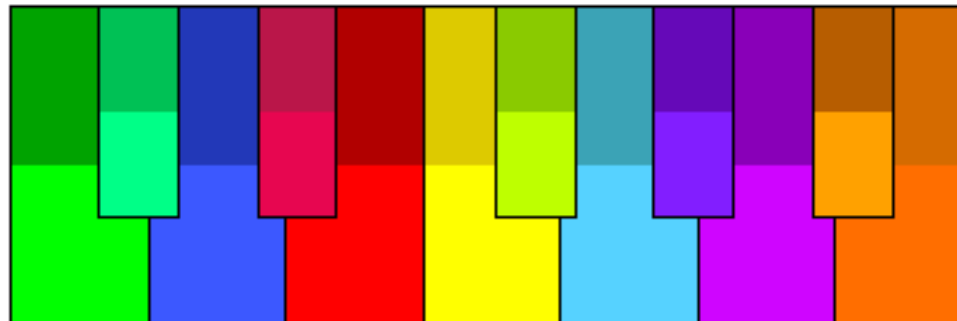
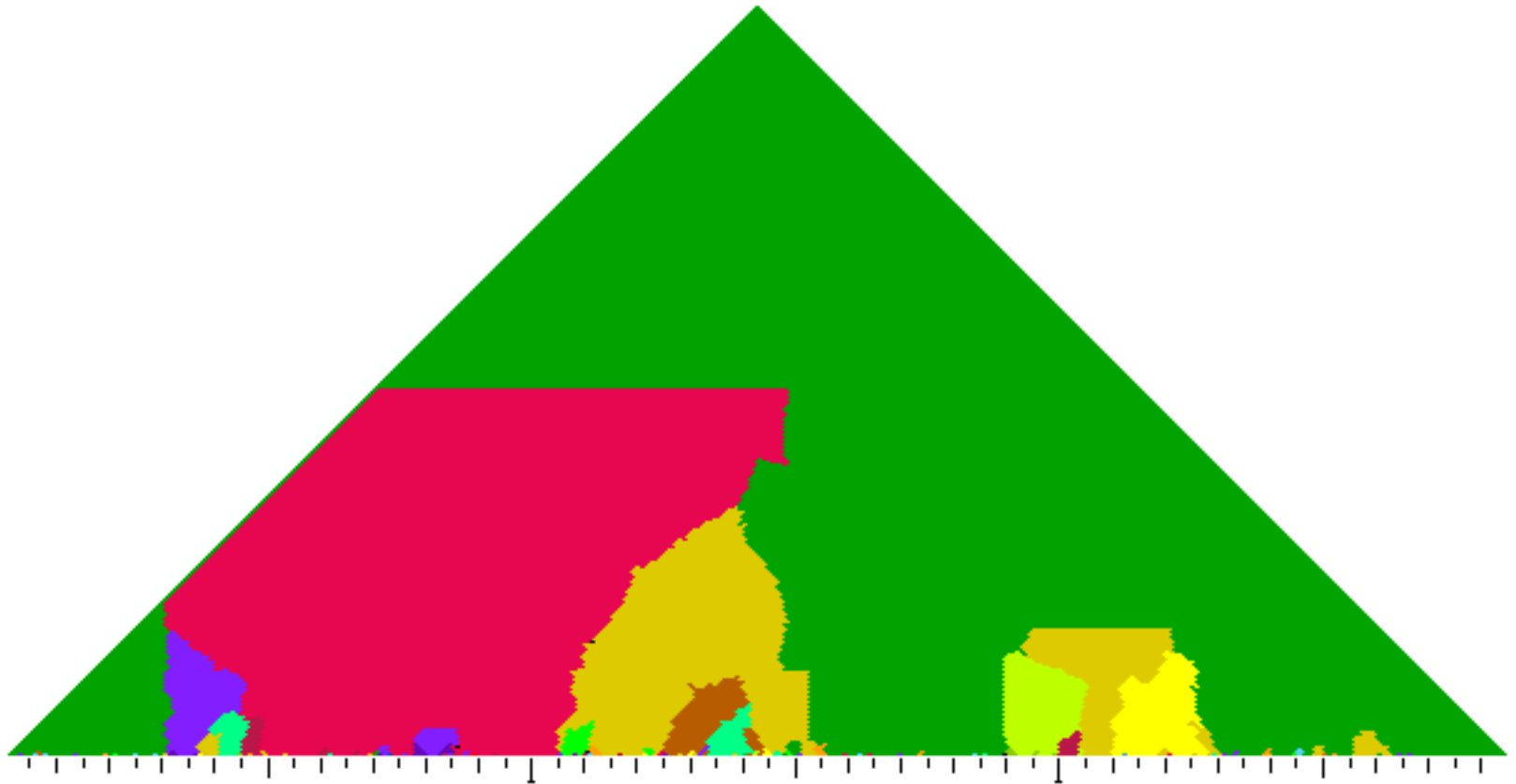
$$\text{key}_k = \arg \max_k r(x, y_k)$$

# Computational Key Identification



pitch-class histogram:  $x = (8, 0, 0, 0, 2, 11, 0, 5, 7, 0, 5, 2)$   
 major key prototype:  $y_M = (2, 0, 1, 0, 1, 1, 0, 2, 0, 1, 0, 1)$   
 minor key prototype:  $y_m = (2, 0, 1, 1, 0, 1, 0, 2, 1, 0, 1, 0)$

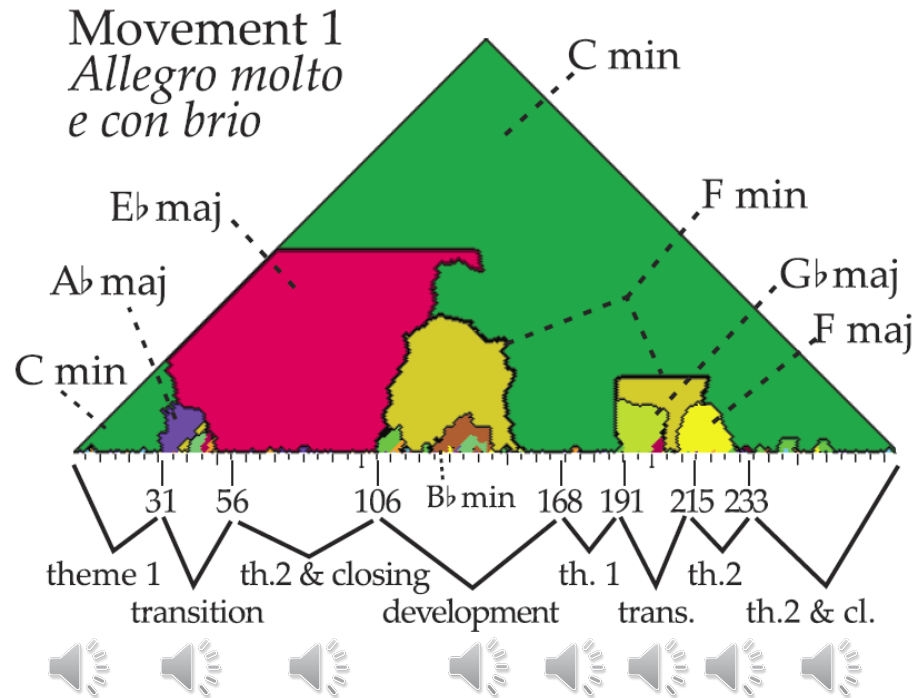
# Beethoven Piano Sonata #5 mvmt 1



# Sonata No. 5 Internal Key Structure

## Theme 1 (C minor):

Movement 1  
*Allegro molto  
e con brio*



## Theme 2 (E♭ major):



## Theme 2 (F major):

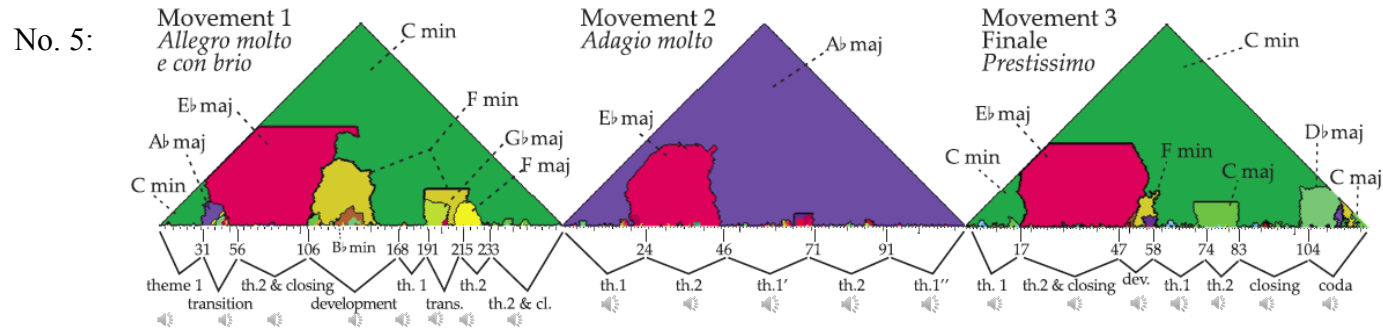


## Theme 2 (C minor):

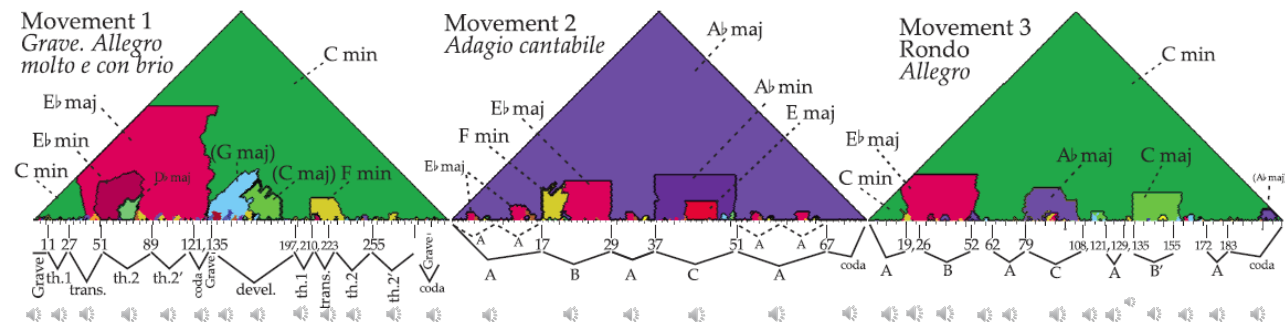




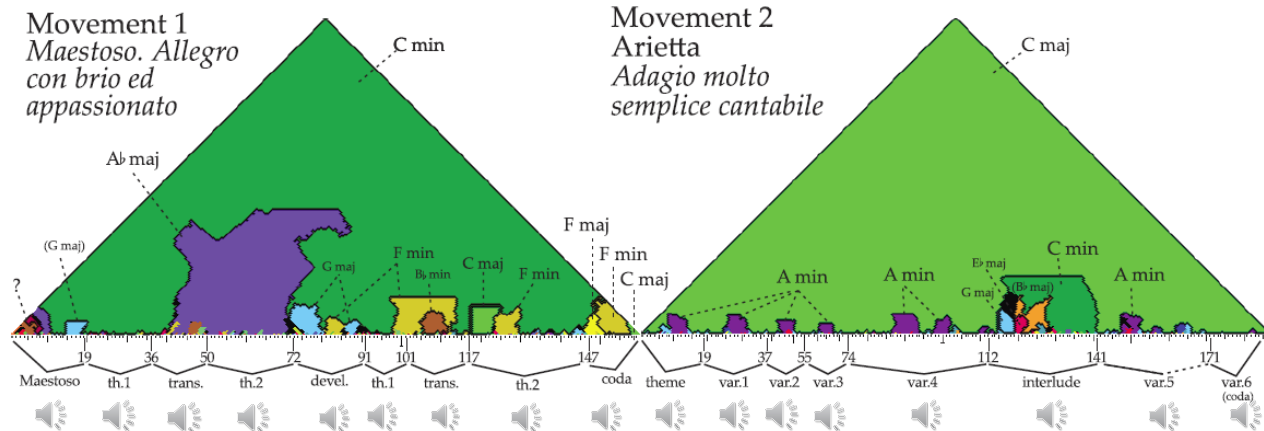
# Other C-Minor Beethoven Sonatas



## Piano Sonata no. 8 in C minor, op. 13 ("Pathétique")



## piano sonata no. 32



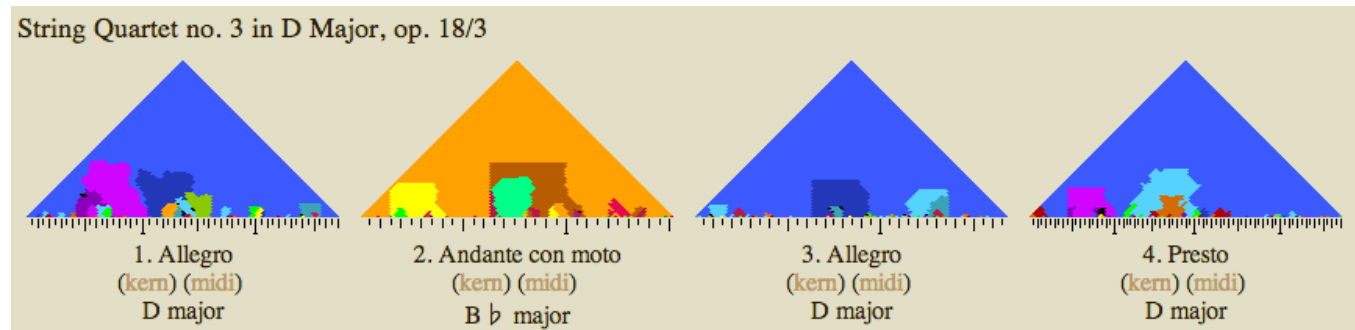
# More Info

## C++ implementation of KS algorithm and keyscape generator:

- <http://extras.humdrum.org/man/keycor>
- <http://extras.humdrum.org/man/mkeyscope>

See bottom of last link for latest keyscape galleries, such as Beethoven string quartets:

<http://extras.humdrum.org/man/mkeyscope/beet-quartet>



## ~5000 keyscales of MIDI files:

<https://ccrma.stanford.edu/~craig/keyscape/class>

# Form Visualization/Analysis

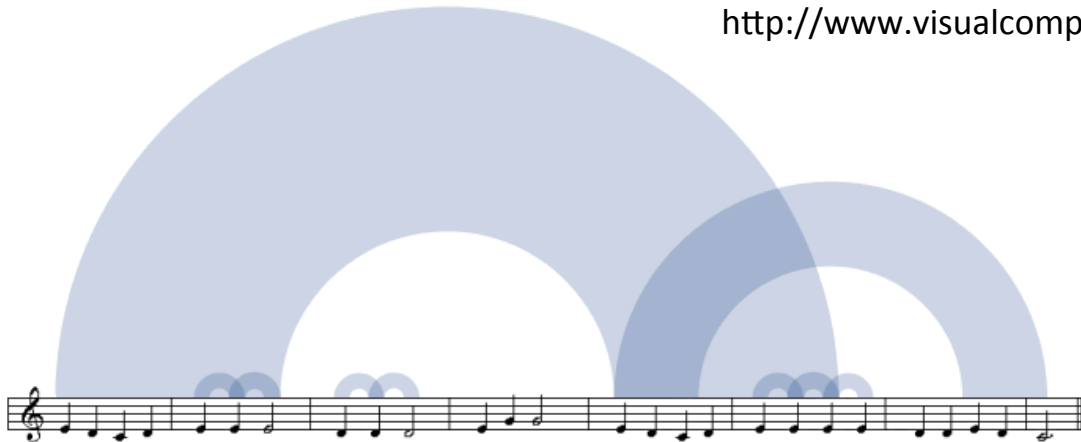
<http://www.bewitched.com/song.html>

<http://hint.fm/papers/arc-diagrams.pdf>

Martin Wattenberg



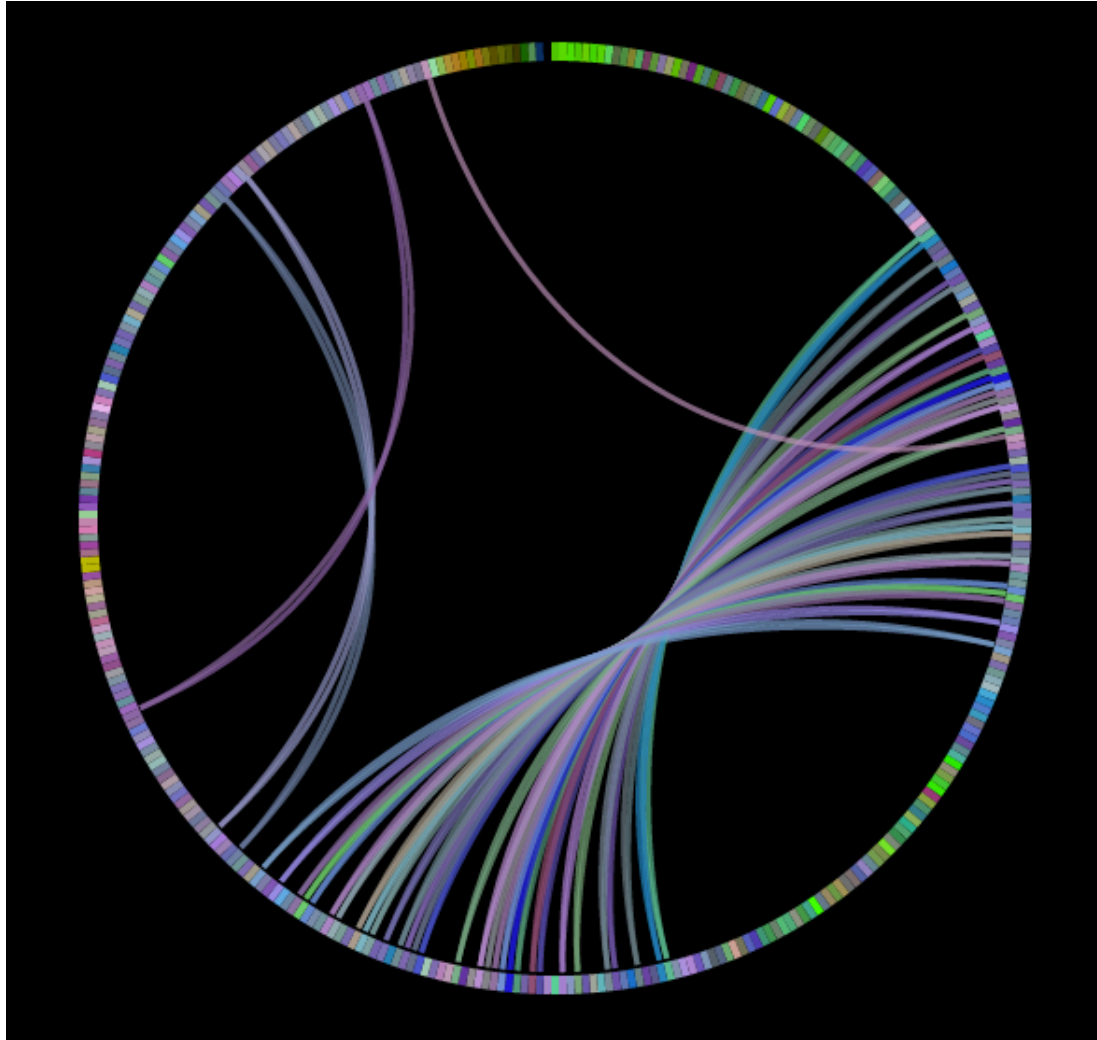
<http://www.visualcomplexity.com/vc/index.cfm?method=Arc%20Diagrams>



# Infinite Jukebox

<http://labs.echonest.com/Uploader/index.html?trid=TRORQWV13762CDDF4C>

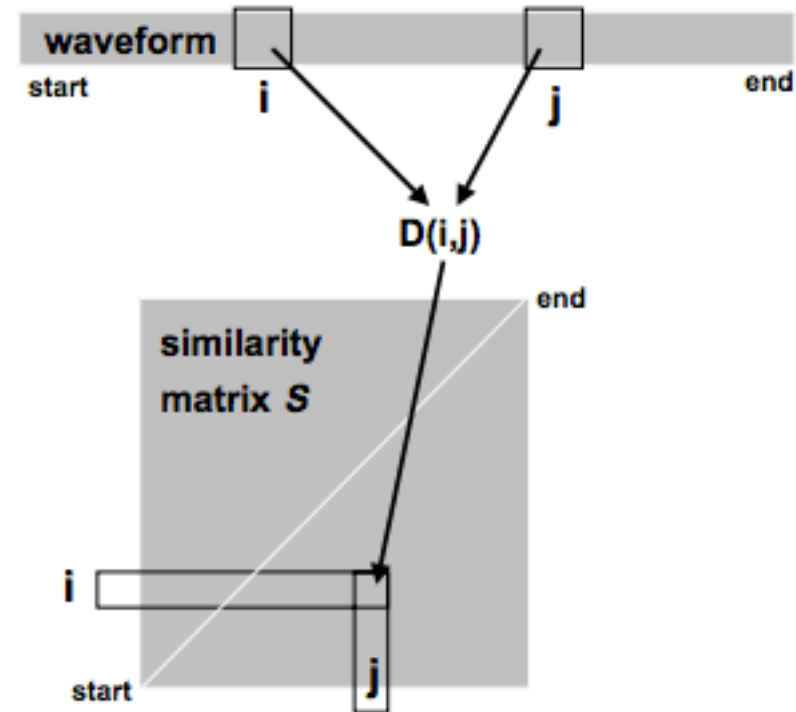
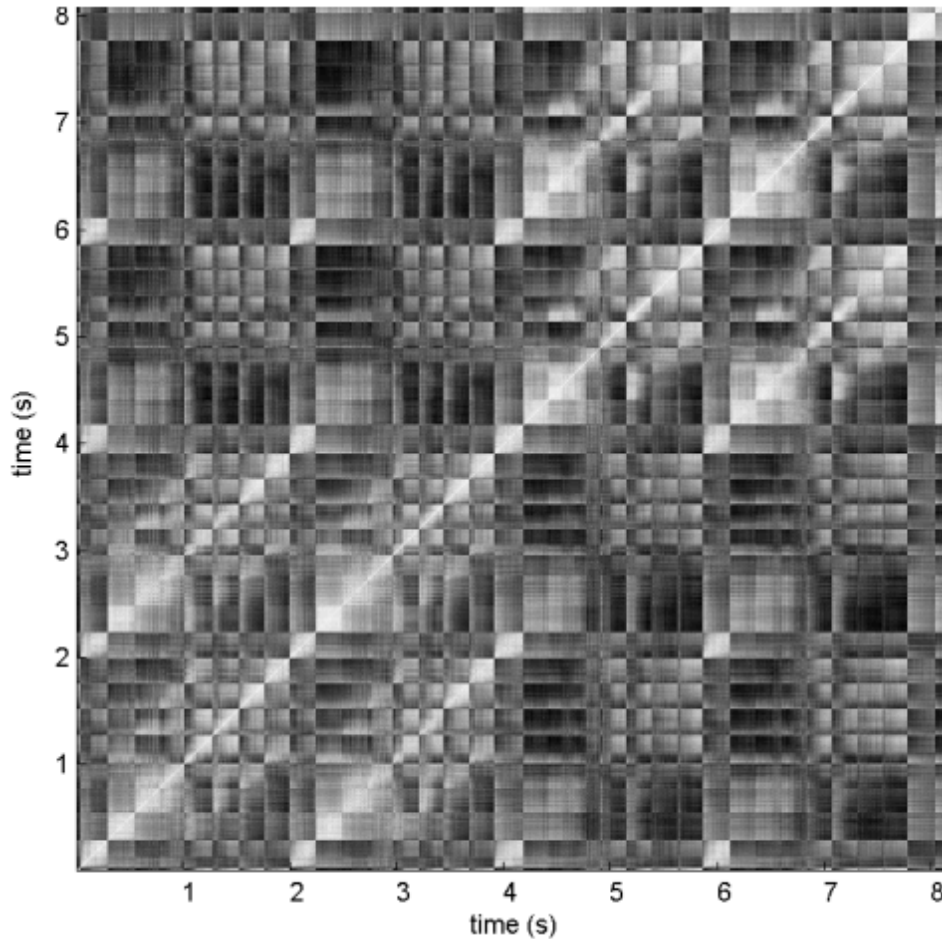
Paul Lamere



# Similarity Matrix

Jonathan Foote

<http://www.fxpall.com/publications/visualizing-musical-structure-and-rhythm-via-self-similarity.pdf>



J.S. Bach WTC 1: Prelude #1 in C major